

Zero Emission Cargo Transport II San Pedro Bay Ports Hybrid & Fuel Cell Electric Vehicle Project

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June 20, 2018

(This presentation does not contain any proprietary, confidential, or otherwise
restricted information) [Project ID # elt158]



ZECT II

Overview

Timeline

- Project Award: 10/1/14
- Contractor Kickoff: 12/16/15
- Project Completion: 9/30/19

Contractors & Projects

- BAE/CTE - Fuel cell range extended drayage truck
- TransPower - Fuel cell range extended drayage truck
- U.S. Hybrid - Fuel cell powered drayage truck
- BAE/GTI - CNG hybrid with Near Zero CNG Engine
- Hydrogenics – Fuel cell range extended drayage truck

Barriers & Challenges

- Fueling Infrastructure: Availability and location
- Costs: Fuel Cells, batteries and infrastructure
- System Integration: Safe and efficient deployment of the technology

Budget

- DoE: \$10,000,000
- Funding partners: \$7,467,473
- Contractors: \$3,075,841

Total Cost:\$20,543,314

Relevance: Goals & Objectives

- **2017/2018 Objectives:**
 - Complete initial vehicle builds
 - Complete the permitting and siting of portable hydrogen fuel
 - Begin vehicle demonstration and data collection
- **Results:**
 - Initial vehicle build completed Q4 2017, testing completed April 2018
 - Portable hydrogen fuel onsite, testing completed March 2018
 - Four trucks started demonstration in May 2018: US Hybrid, TransPower, Kenworth FCEV's and Kenworth CNG Hybrid
- **Impact:**
 - **Pushing Zero Emission Technology and Industry Envelope by Demonstrating First Fleet of FCEV's in Drayage Service in California**



Remaining Challenges and Barriers

- **Fueling Infrastructure: Availability and location**
 - All temporary hydrogen fueling is in place and being used for the demonstration
 - Permanent stations will be a challenge – SCAQMD is working with partners on a solution
- **System Integration: Safe and efficient deployment of the technology**
 - Six of seven vehicle designs and integration are complete, demonstration started in May
 - Complete build of 2nd US Hybrid and TransPower vehicles and the Hydrogenics vehicle
- **Costs: Fuel Cells, batteries and infrastructure**
 - Costs will remain a challenge for the near and mid term
 - Costs of batteries followed by fuel cells will continue to fall as the light duty BEV's and FCEV's markets expand



Technical Progress: Hydrogen Station

- ✓ Hydrogen supplier Air Products delivered and commissioned fueling stations at Kenworth test sites and Port of LA demonstration site:
 - ✓ Renton and Mt. Vernon, WA, have been commissioned to provide fuel for vehicle testing
 - ✓ San Pedro, CA, has been commissioned and will remain active throughout the vehicle demonstration period for all vehicles under this program
- ✓ Developed coordinated and completed:
 - ✓ Site improvements
 - ✓ Hydrogen supply and delivery
 - ✓ All station permit applications and processes



Photo: Kenworth

Fueling station at Mt. Vernon



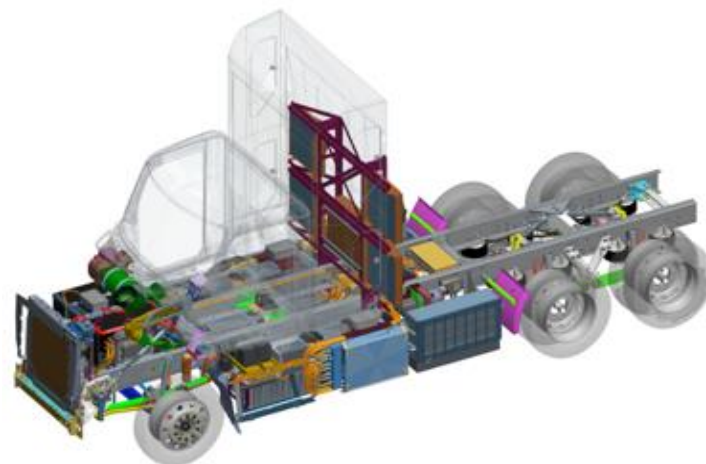
Photo: CTE

Fueling station at San Pedro

Technical Progress: Fuel Cell Truck Integration

Last year, architecture was finished, simulated, and the design review was completed. This year:

- ✓ Ballard fuel cell and related equipment were mounted and tested
- ✓ Design and integration of traction motors into transmission assembly was completed
- ✓ Regenerative braking and automatic transmission shifting were debugged and tested
- ✓ Improved charging system was designed, built, tested, and installed
- ✓ Custom electric auxiliary components were built and integrated
- ✓ Cooling system was integrated
- ✓ Hydrogen storage system was fully integrated and tested
- ✓ BAE hybrid system components were mounted



Last Year: Truck Designed

Illustration: Kenworth



This Year: Truck Fully Integrated

Photo: Kenworth

Technical Progress: Fuel Cell Truck Integration

- ✓ Validated performance of dual traction motors and transmission
- ✓ Completed system-level and vehicle-level tests of all integrated components
- ✓ Tested at expected worst-case driving conditions
- ✓ Dynamometer and early road testing indicated truck was on track to meet program requirements

Initial Dynamometer Test



Photo: Kenworth

Functional Road Test & Vehicle Commissioning



Photo: Kenworth

Technical Progress: Fuel Cell Truck Integration

- ✓ Developed and coordinated:
 - ✓ Training for station staff
 - ✓ Training plans for operations and maintenance
 - ✓ Dealer support plans
 - ✓ Manuals for vehicle operation and maintenance
- ✓ CTE conducted training for First Responders in the local San Pedro, CA area

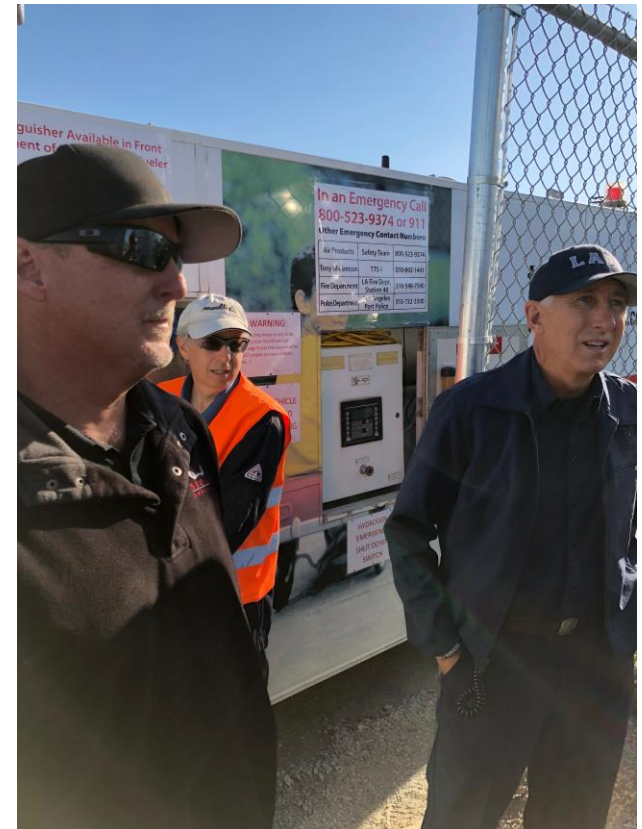
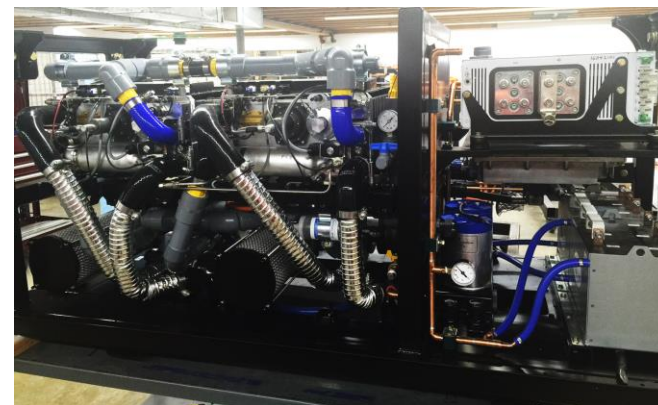


Photo: CTE

First Responder training in San Pedro, CA

Technical Progress: Fuel cell Vehicle Build

- Truck Frame rails were extended because some trailers were interfering with fuel cell power module when turning
- Fuel Cell Dual Hydrogenics FC-30 tested and installed
- Fuel Storage installed
- Battery: Tested and installed
 - Cumulative heating of battery may be an issue at elevated ambient temperatures - exploring thermal management solutions



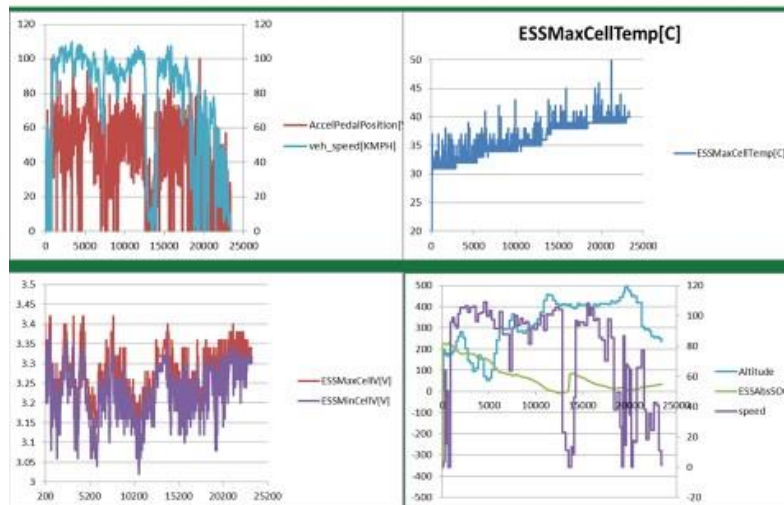
Fuel Cell Power Module (FCPM)



Fuel, FCPM behind Cab of Truck

Technical Progress: Fuel cell Vehicle Build

Two hours of data, driving from Escondido to Riverside TransPower

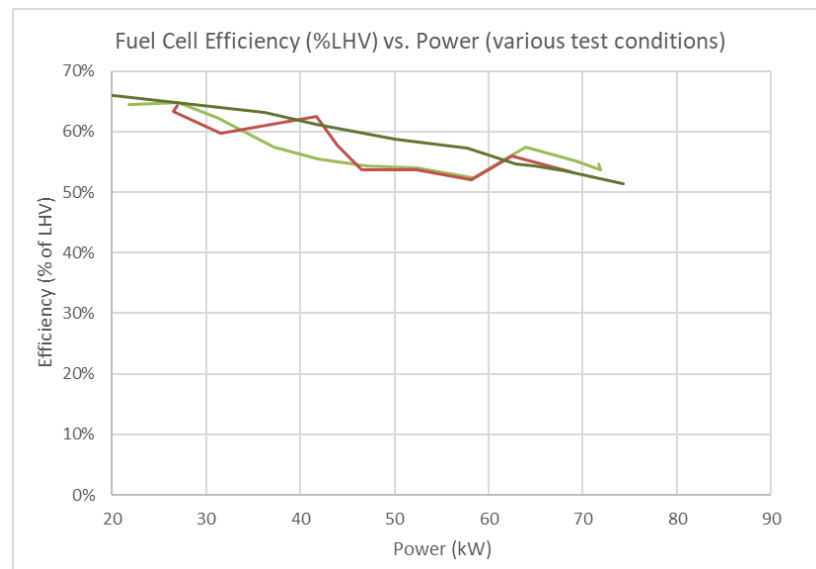
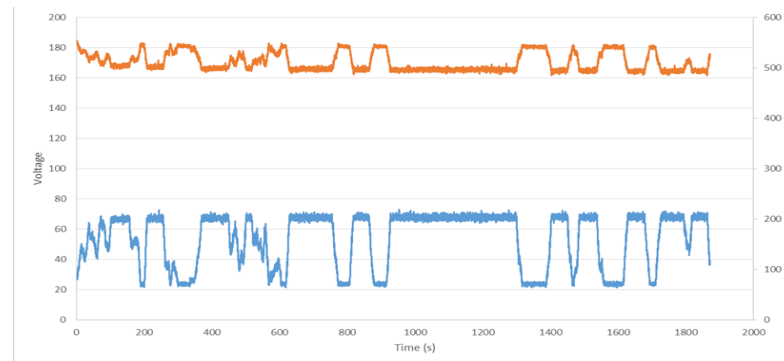


- Prototype Fuel Cell Truck has been commissioned, driven 1650 miles with and without trailers
- Truck was exhibited at Fuel Cell Seminar in November 2017
- Daily mileage in double digits - 200 miles maximum
- First responder training complete
- Second truck being fabricated
 - Major systems completed
 - Fuel cell undergoing stationary commissioning



Technical Progress: Fuel cell Vehicle Testing

- The 80kW Fuel Cell module was integrated with the truck and completed road testing
- FCe80 Efficiency exceed the project target of 50% with 57% tested



Technical Progress: Fuel cell Vehicle Testing

- US Hybrid's first H₂truck completed:
 - Road testing
 - Fueling at customer site
 - Customer training for deployment
- Truck has been presented to potential customer for pre-commercial sales
- H2Truck #2 is under production



Technical Progress: CNG Hybrid Truck Integration

Production Kenworth T680 Daycab Modifications:

- Cummins Westport Inc. Near-Zero ISL-G Engine
- BAE generator, propulsion control systems, power interface module, dc/dc converter
- Custom Dual-Remy ACTM
- XALT 100kWh battery packs
- Custom electric 650V A/C compressor, air compressor, power steering



Technical Progress: CNG Hybrid Truck Integration

- **Full Truck Integration Is Complete**
 - Truck assembled at Kenworth facility in Renton, WA
 - Smart charging port designed built, tested, and installed
 - Chassis completed with hybrid drive system
 - Battery system and preliminary vehicle level functional tests and commissioning completed



Shore Power Charging Port



Operational Hybrid Truck

Technical Progress: CNG Hybrid Truck Integration

- **Operational Testing Has Begun**
 - Chassis was moved to PACCAR Technical Center (PTC) in Mount Vernon, Washington
 - Test plan includes extensive component, system and vehicle testing under different loads and environmental conditions
 - Tests will verify range limits in EV & HEV mode with full and empty loads for steady state and simulated routes
 - Testing continues without significant issue to date



Technical Progress: Fuel Cell Truck Integration

- Electric Drive - Siemens drive system expected to be delivered mid of 2Q/2018
- Communications and Control - Daimler provided chassis CAN information including vehicle controller roll call check on vehicle startup
- Electric Schematics - Continue to update 24V schematics for complete truck
- Accessories Procurement and Packaging - A/C compressor, Power steering, HV power distribution center



SIEMENS



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Technical Progress: Fuel Cell Truck Integration

- Fuel Cell System and Cradle:
 - Test fit and brackets finalized for mounting Celerity fuel cell power system in truck
- Battery System:
 - First pack 80% complete by the end of quarter, BMS wiring will be completed early 2Q/2018, coolant flow plumbing 100% completed
 - Second pack assembly originally scheduled for completion mid March is expected to be completed towards end of 2Q/2018.



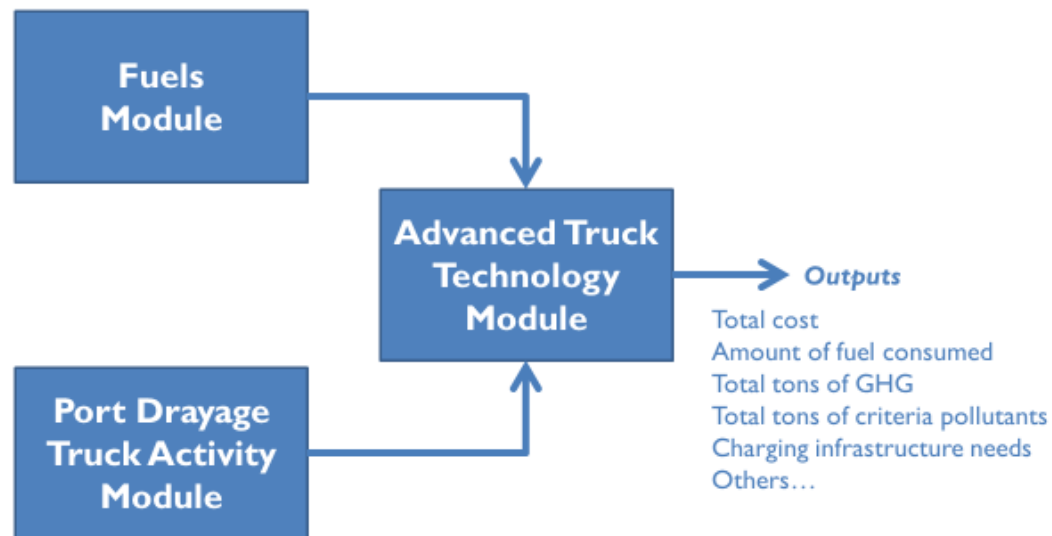
Technical Progress: Fuel Cell Truck Integration

- Hydrogen Fuel Storage System
 - 350 bar Hydrogen fuel storage system from Agility has been received, inspected and mounted to chassis
- Schedule:
 - Design and Procurement Phase 1 80% complete
 - Critical Project Review meeting with CEC held on February 26, 2018
 - Project schedule expected to be impacted due to additional battery chemistry evaluations



Future Research: Commercialization

- Model elements for commercialization roadmap
- Identify business case for EV drayage with CNG range extender
- Evaluate roll-out plan



Response to Reviewers Comments

The reviewer observed this project has big bucks, but the approach seems to be to just try this and that and one of those, because it will probably work. There does not seem to be any background plan of what types of features might be most useful for different vocations, with an attempt to design vehicle characteristics to match needs. The reviewer remarked each design is well thought through and technically sound, but the project team should figure out which make sense and focus on those. The reviewer suggested the different types of trucks need to be compared to each other and to conventional alternatives. (Reviewer 4)

Our contractors are aware of what the customer requirements are as well as the duty cycles they put their vehicle through. We chose our contractors for their experience and track record in the industry. They know that there are many approaches to solving the “problem” each having its own merits. Our technology partners are addressing cost, weight, packaging challenges as well as efficiency, range and payload capacity by varying the size of the battery, fuel cell and hydrogen storage. Modeling that took into account the different duty cycles in drayage operations were used when simulating the various system architectures. All contractors subjected their vehicles to a dyno test programmed with the same drayage duty cycles that were developed with conventional vehicles. Since there are variety of customers and duty cycles it seems advantageous to use a variety of approaches. SCAQMD does not dictate what design our partners use or how they develop their vehicles rather we try to determine if there design will satisfy their intended customer and duty cycle. Truck OEM’s manufacture and market a variety of engine sizes, transmissions and axels for their vehicles to serve a variety of customers and needs; likewise so will they do for zero emission power trains.

The reviewer stated technical progress seems alright on vehicles (although difficult to gauge with so many combinations and approaches). There is little mention of progress on fueling infrastructure, which is identified as a significant barrier on this project. (Reviewer 2)

From our presentation we can see that the hydrogen fueling is now in place but the amount of time and effort was more extensive than was anticipated for portable refueling. Several permits were required, followed by an exhaustive review process. Every permitting authority had different requirements including the port, the fire marshal and the City of Los Angeles. A permanent source of fuel is still being investigated by SCAQMD and our partners but for this project a permanent station could not be justified. We believe this technology will play a significant role in reducing emissions in the South Coast and so our efforts for heavy duty vehicle hydrogen refueling standards and infrastructure will continue.

ZECT II Summary

- Temporary hydrogen refueling permitted, installed and tested – providing H2 fuel for demonstration
- BAE and Kenworth completed vehicle design, analysis, equipment purchase, vehicle build and testing– vehicles being demonstrated at San Pedro Ports
- TransPower and U.S. Hybrid first trucks completed build and testing – vehicles being demonstrated at San Pedro Ports
- TransPower and U.S. Hybrid continue work on their second trucks
- Hydrogenics continues to make progress in the design and build of truck for DOE ZECT project
- Research: A model is being developed to enable different adoption scenarios to be input and provide output emissions savings and vehicle counts (other factors TBD)

